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OCEAN WATER COLOR ASSESSMENT FROM ERTS-1 RBV AND MSS IMAGERY
MMC #538

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D. S. Ross PR 175

International Imaging Systems

510 Logue Avenue

Mountain View, California 94040

7 July 1973

Progress Report for Period 8 May 1973 - 7 July 1973

Prepared for

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND 20771

MMC #538 - OCEAN WATER COLOR ASSESSMENT

FROM ERTS-1 RBV & MSS IMAGERY

D. S. ROSS PR175

PROGRESS REPORT, PERIOD 8 MAY - 7 JUL 1973

CONTRACT NAS5-21862

1. Objective. The objective of the contract is to determine whether or not it is feasible, by interactive image processing, to separate image densities representing ocean scene reflectances in the 460-490 nm region, from the full 460-580 nm band recorded by ERTS-1 RBV-1. By so doing, an indication of blue and green water color ratios may be obtained as an indication of fertility for fish populations. The method employed is based on photographically masking the RBV-1 image with an MSS-4 image of opposite polarity. As the MSS-4 records a 490-600 nm band, subsidiary masking with RBV-2 (580-680 nm) is required to remove image densities attributable to 580-600 nm scene reflectances. Additionally, masking to reduce residual radiometric correction errors is used.

2. Summary of Work During Period. Radiometric error correction masking on the RBV-1 and -2 images was completed, and these images were remade at higher gammas to offset atmospheric

scene contrast degradation effects. A new image was made by combining RBV-2 pos and MSS-4 neg at matching gamma, to cancel image densities in the 580-600 nm spectral region. The resulting image appears to show this effect in the shallow water areas, but density reproduction control for the next step was judged to be inadequate. Re-calculation of atmospheric haze effects and the less than γ 1.0 sensor reproduction of the original in the dark areas shows that scene reproduction gammas in the images to be worked with require additional corrections. Work has been re-started and different methods of gamma and density control are being employed for improved control.

3. <u>Conformance with Work Schedule</u>. Delays in receiving imagery, beyond the control of GSFC and this investigator entailed the submission of a new Data Handling Plan, which was approved 17 Apr 73. Current work is on schedule, but the delay in starting will cause completion of the project to be in December 1973, rather than August 1973. A request to extend completion date, at no additional cost to the Government, has been submitted to the Technical Monitor.

Progress

4. Correction masks for reducing residual radiometric shading errors were made as described previously, and applied to RBV-1 and -2 images of ERTS-1 image set 1007-15165, 30 Jul 72 (Caribbean area) for generating corrected negatives. Estimation of scene contrast reduction, due to atmospheric effects, was made by measuring image densities of light and dark subjects (Cloud and water areas) for gamma correction in reproducing the RBV-1 and MSS-4 images to contrast ranges more nearly representing their true ground level albedo. Initially, RBV-1 and -2 were reproduced at γ 3.85 as positives, and MSS-4 as a negative at the same γ.

5. RBV-2 pos and MSS-4 neg were combined in registration and a masked positive was made at γ 1.0, to preserve the contrast of the γ 3.85 working images. The objective was to produce a new image containing water image densities in the 490-580 nm range. The MSS-4 image covers a 490-600 nm spectral scene range, and the RBV-2 a 580-680 nm range. The clear, calm ocean water surface makes little or no spectral contribution to the image above 580 nm, and the water surface in this spectral region would be near Dmax in the RBV-2 positive, and clear in the negative; when combined with the 490-600 nm MSS-4 positive, scene reflectances above 580 nm would be

masked on the land areas, or where light in very shallow water is reflected from the bottom; but the surface of the deep water would print through. The masking effect was found in a shallow area between North and South Bimini Islands, and is shown in Figure 1.

Problems

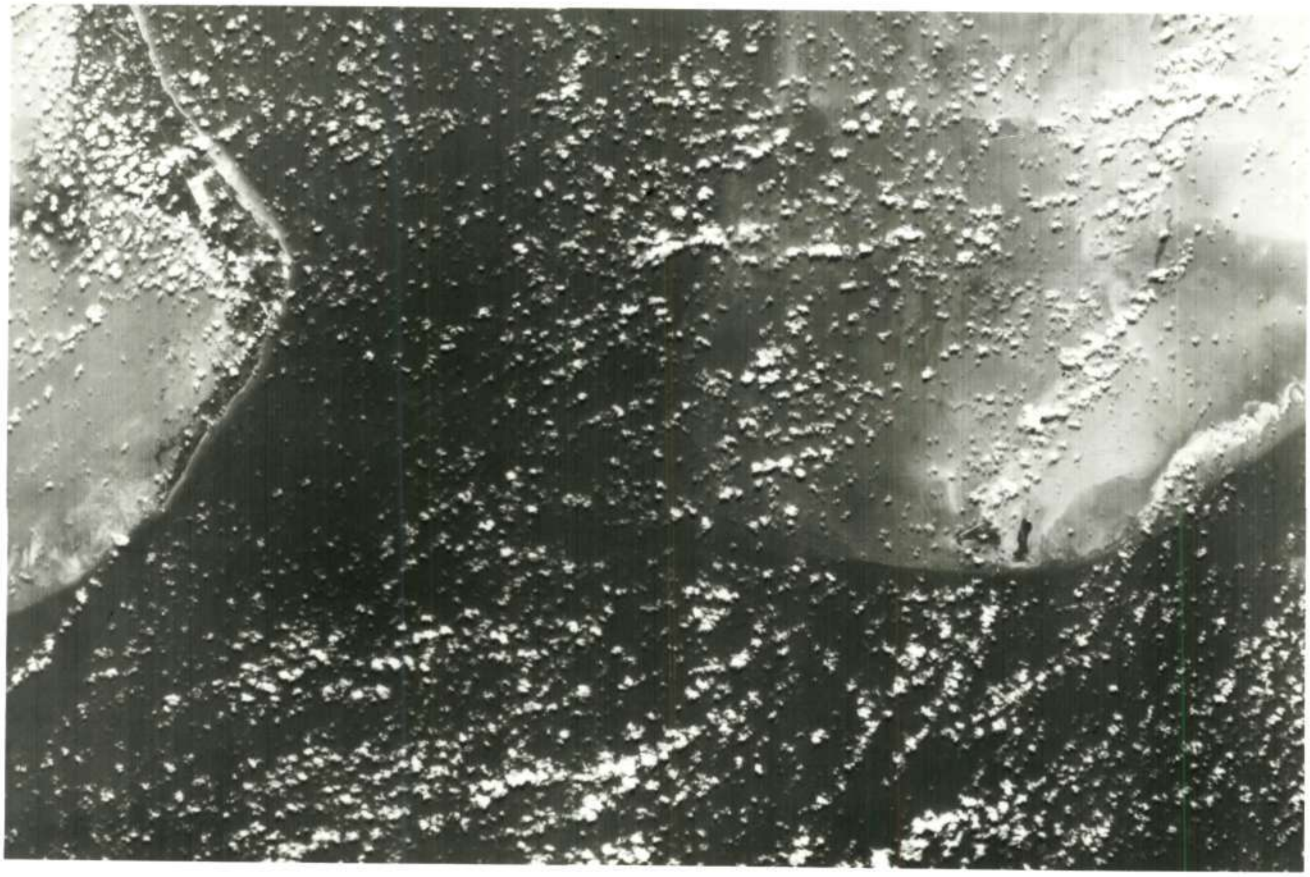
6. Great difficulty was experienced in maintaining exposure and density control to ensure the proper level of masking, although use was made of cloud and water image areas for reference, and related densities in the GSFC 15 step tablet. The steps in the latter and their density increments do not lend themselves to convenient sensitometric control. Images of the same clouds, deep water and shallow areas in each spectral band, were used for exposure control in reproducing the range of image densities concerned on the straight line part of the reproduction film, in each case. Because high gammas were entailed, straight line image densities became very high when negatives and positives were combined for reproduction, net densities being above 5.0 in some cases, and control based on image densities alone eventually became undependable.

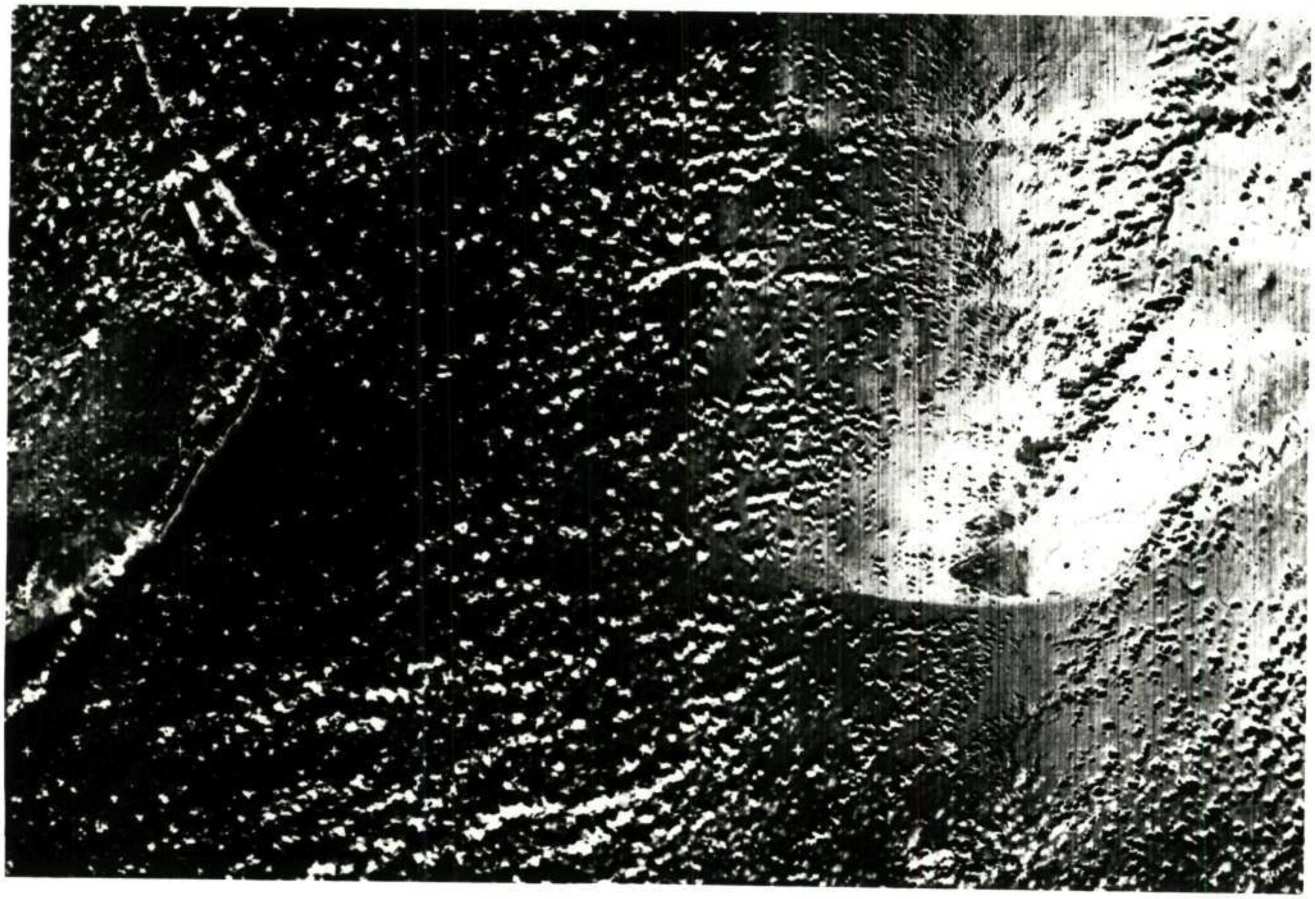
Figure 1 (Photographic Print)

ERTS 1007-15165, 30 Jul 1972

Left, Print made by masking RBV-2 positive image with MSS-4 negative at controlled gammas and densities. A 20 nm yellow spectral region of bottom reflectance in the water has been suppressed between North and South Bimini Islands, in the lower part of picture. The same effect is found in the shallow water north of Grand Bahama Island, at the top of the picture.

Right, Unmasked MSS-4 image for comparison.





7. It also became apparent that the image densities of primary importance, the ocean surface, were being affected during reproduction by their departure from γ 1.0 in the original, and work with this set of reproductions was halted to reexamine the problem.

8. The RBV images match each other for registration, but do not match the MSS-4 image. A best fit is made in the north-south central parts in registering the RBV and MSS images, since this is the main area of deep and shallow water under examination. Images corrected for geometric fidelity would be likely to lose some of the small gradations in image density information sought and their use is not proposed.

Current and Planned Work

9. The RBV-1 and -2 images, and the MSS-4 have been hand-registered and punched for registration pins. A template with pins has been made to hold the images during printing, and also to locate a series of calibrated 21-step-tablet exposures in different locations on the reproduction films, in a sequence which will permit more positive control of each phase of reproduction, processing and masking. The $\sqrt{2}$ density step progression will also enable measurements to be more closely related to the significant image densities, when working with the high net densities noted in para 3.

10. <u>Masking Schematic</u>. Figure 2 is a more complete diagram of the various reproduction and masking steps involved in the process, and supplants the Schematic shown as Figure 2 in the 7 May 1973 Progress Report.

11. <u>Normalizing Image Densities, and Atmospheric Effects</u>. The following assumptions have been made in normalizing image densities, for the estimation of differences in atmospheric effects between the different spectral bands:

a. Image densities are linear over a 2.0 D range, within the 0.4 D to 2.4 D, $\pm$.12 D ERTS positive film reproductions being used for the experiment.

b. Within the positive 2.0 D range, 0.0 D represents 100%, and 2.0 D 0% sensor response; thus the density of heavy white cloud would be 100% response; this in turn is checked against the density of the lightest step on the 15-step tablet printed with the image. The two densities should be about equal, deviations being due to local exposure and processing differences in the reproduction. This was confirmed by measurement.

c. As noted in (a), the minimum density in the positive (100% sensor response) is made high enough - 0.4 D $\pm$ .12D - to ensure all image densities are on the

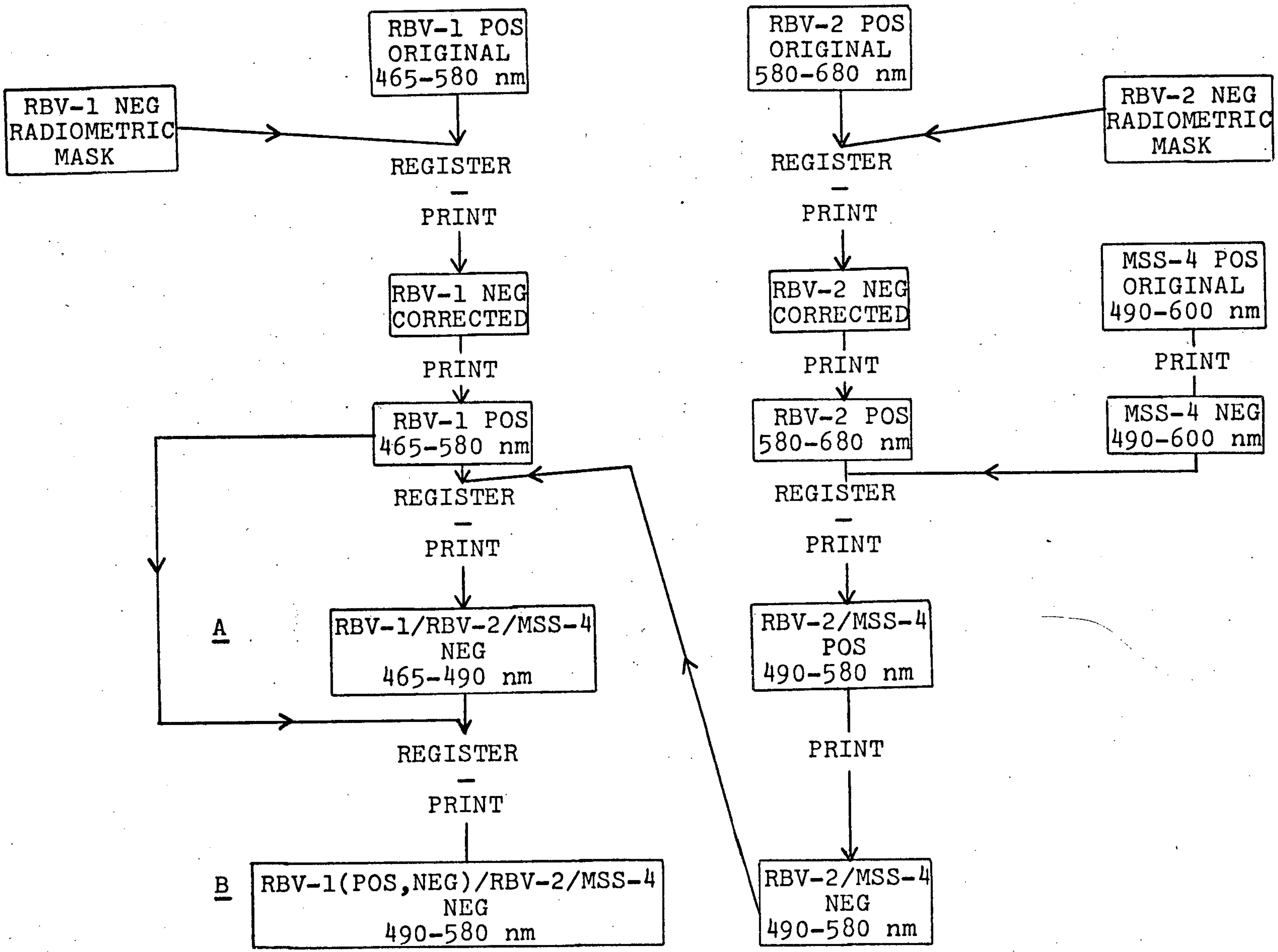


FIGURE 2 - Masking Diagram

straight line of the reproduction curve; if a cloud has 0.50 D, this is 100% sensor response, and 0.50 D should be subtracted from other image densities to find their proper relationship to sensor response on a 0% to 100% scale.

d. However, densities representing less than 20% of full scale sensor response are reproduced at gammas less than 1.0*. If this effect is plotted with density against $\log_{10}$ percent sensor response, the curve shown in Figure 3 results. The dark parts of the positive image falling on the curved line have less contrast, and less density than they should. In effect the curved line shows the non-linearity of sensor response.

The effect of (d) is critical to images of the ocean part of the scene, which is generally recorded well below 20% sensor response. Because of this, and the difference in scene contrast compression caused by the atmosphere between the green and red regions, corrective action is necessary to adjust image contrast to a level more representative of the real values, before images from the two bands can be combined for masking; otherwise, spurious effects will result.

* Data Users Handbook, Appendix H

% Max Sensor Output	Gradient (Gamma)	Normalized γ 1.0 Film D	Effective Film Density
2.0	0.75	1.70	1.27
3.2	0.80	1.50	1.20
5.0	0.85	1.30	1.10
8.0	0.90	1.10	0.99
12.7	0.95	0.95	0.90
20 Plus	1.00	0.70	0.70

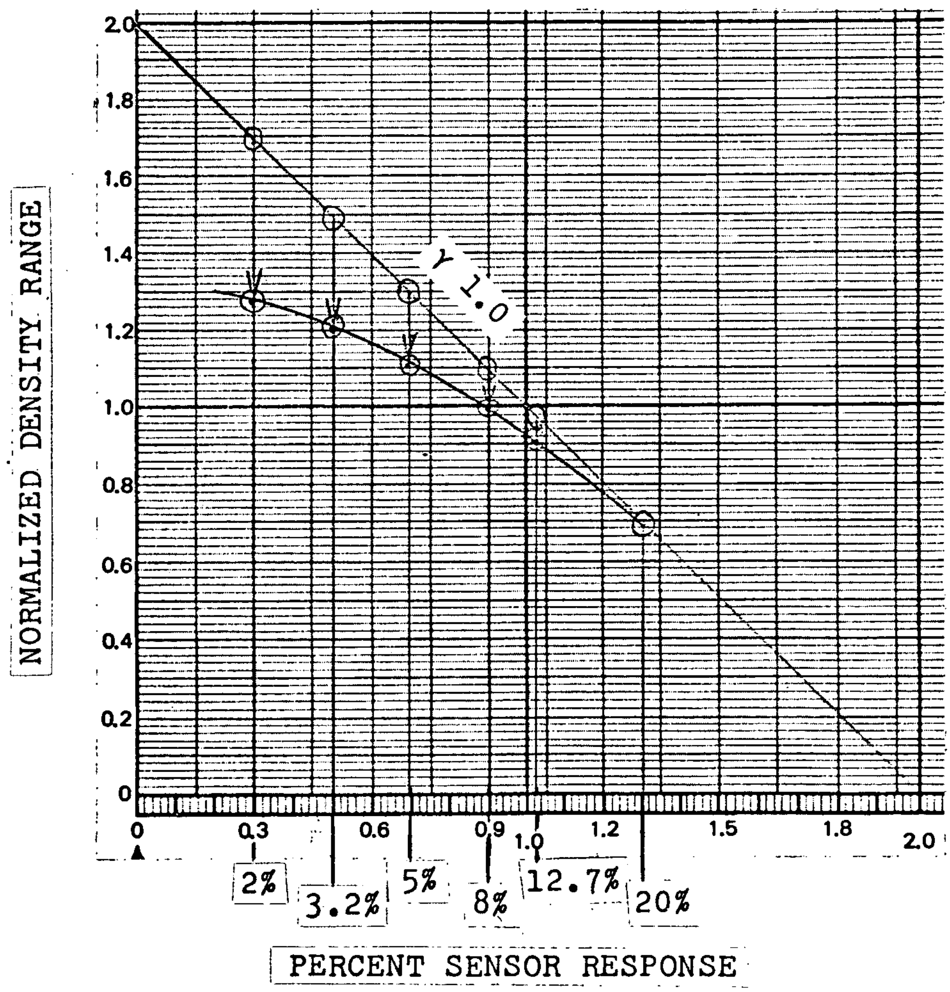


Figure 3 - γ 1.0 line represents linear sensor output plotted against positive image density, where 100% response is 0.0 D and 0% is 2.0 D. Sensor recording gradient (gamma) is less than γ 1.0 between 2% and 20%, resulting in decreased densities and contrast in the darker image areas, as shown by the curved line. Effective density is found by multiplying the theoretical γ 1.0 density by the actual local gamma, viz 1.70 D x γ 0.75 = 1.27 D. Average gamma between 4%-10% is 0.60.

12. In Figures 4, 5 and 6, image densities for the same cloud, deep water and shallow areas in MSS-4, -5 and -7 have been normalized by subtracting the cloud densities as in the procedure described in (c) above, the corrected densities being plotted on the respective curves. MSS-7 has been used as a control for the other bands in evaluating atmospheric effects, since these are least in the MSS infrared region, and a calm, deep, clear water ocean surface should approach D_{max} as IR absorption will be almost complete. In the MSS-7 image, the normalized water density should therefore represent the lowest spectral reflectance in the scene, and the lowest percentage of sensor response, on the assumption that percent scene spectral reflectance within any MSS band is equivalent to percent sensor response.

13. The relative percentages of sensor response/scene reflectances as viewed and recorded from the sensor through the atmosphere, are found by dropping lines from the image subject densities to their corresponding abscissa values, as shown in the Figures. The following is obtained, percent scene reflectance being the antilog of sensor response:

B

SENSITOMETRIC DATA SHEET

International Imaging Systems

DATE: 3 July 73

PROJECT NO.: C-200

PREPARED BY: D. S. Ross

ERTS-1 IMAGE SET 1007-15165 (A)

LOCATION CARIBBEAN

~~RBV~~/MSS BAND 4

DATE 30 Jul 72

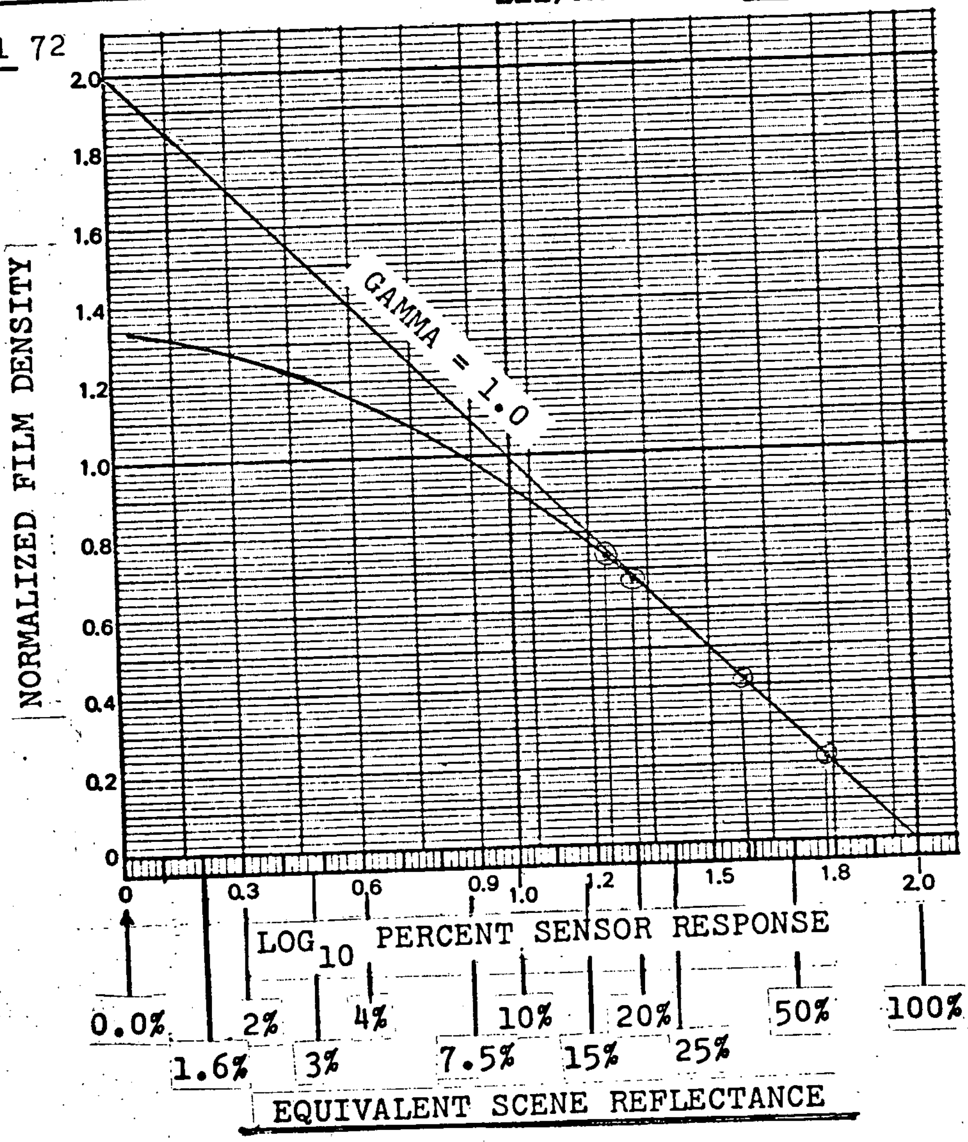


IMAGE CONTROL DENSITIES

		LESS CLOUD 0.50 D
CLOUD	0.50	0.00
DEEP WATER	1.17 - 1.23	0.67 - 0.73
SHALLOW WATER	0.71 - 0.91	0.21 - 0.41

Figure 4

International Imaging Systems

SENSITOMETRIC DATA SHEET

PROJECT NO.: C-200

DATE: 3 Jul 73

PREPARED BY: D. S. Ross

ERTS-1 IMAGE SET 1007-15165 (A)

LOCATION CARIBBEAN

~~RBV~~/MSS BAND 5

DATE 30 Jul 72

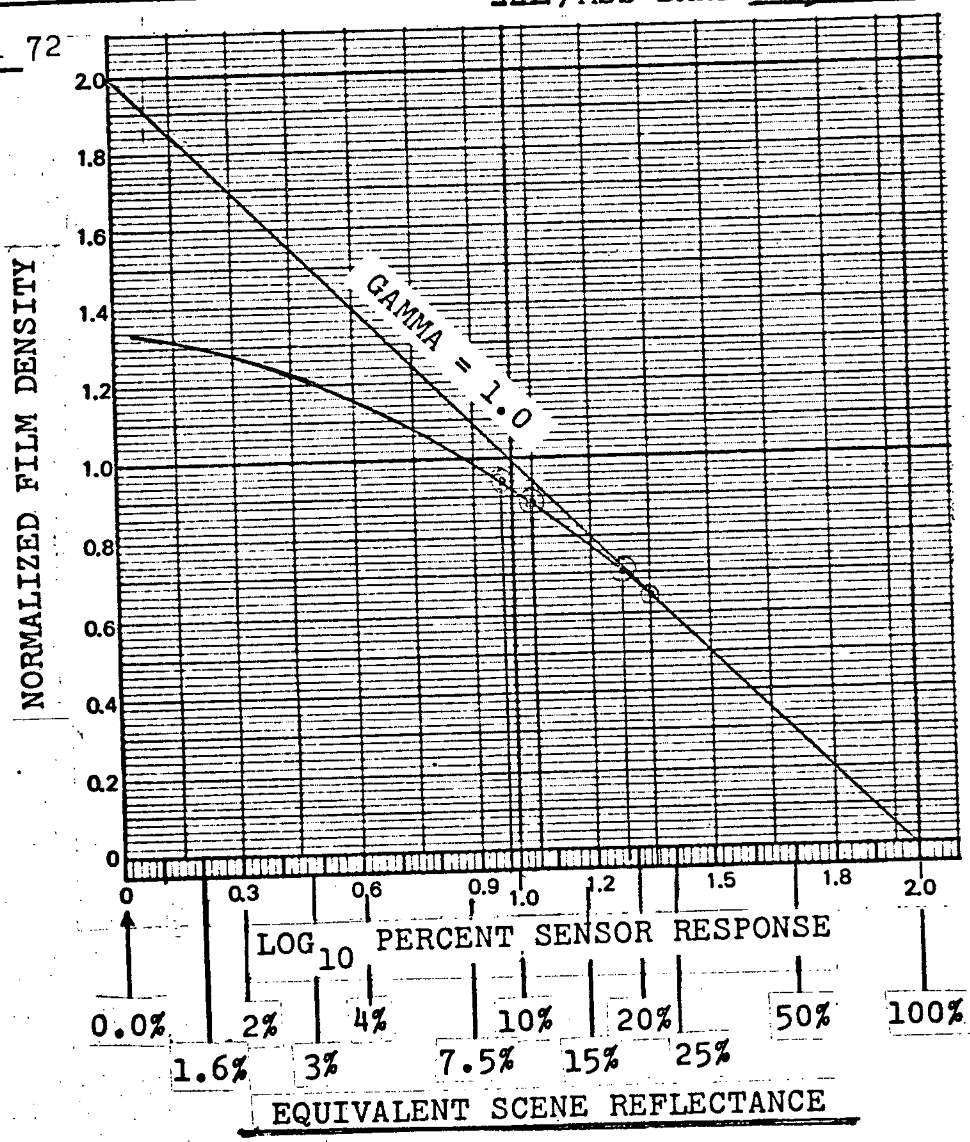


IMAGE CONTROL DENSITIES

		LESS CLOUD 0.49 D
CLOUD	0.49	0.00
DEEP WATER	1.37 - 1.43	0.88 - 0.94
SHALLOW WATER	1.13 - 1.19	0.64 - 0.70

Figure 5

International Imaging Systems

SENSITOMETRIC DATA SHEET

PROJECT NO.: C-200

DATE: 3 Jul 73

PREPARED BY: D. S. Ross

ERTS-1 IMAGE SET 1007-15165 (A)

LOCATION CARIBBEAN

~~RBV~~/MSS BAND 7

DATE 30 Jul 72

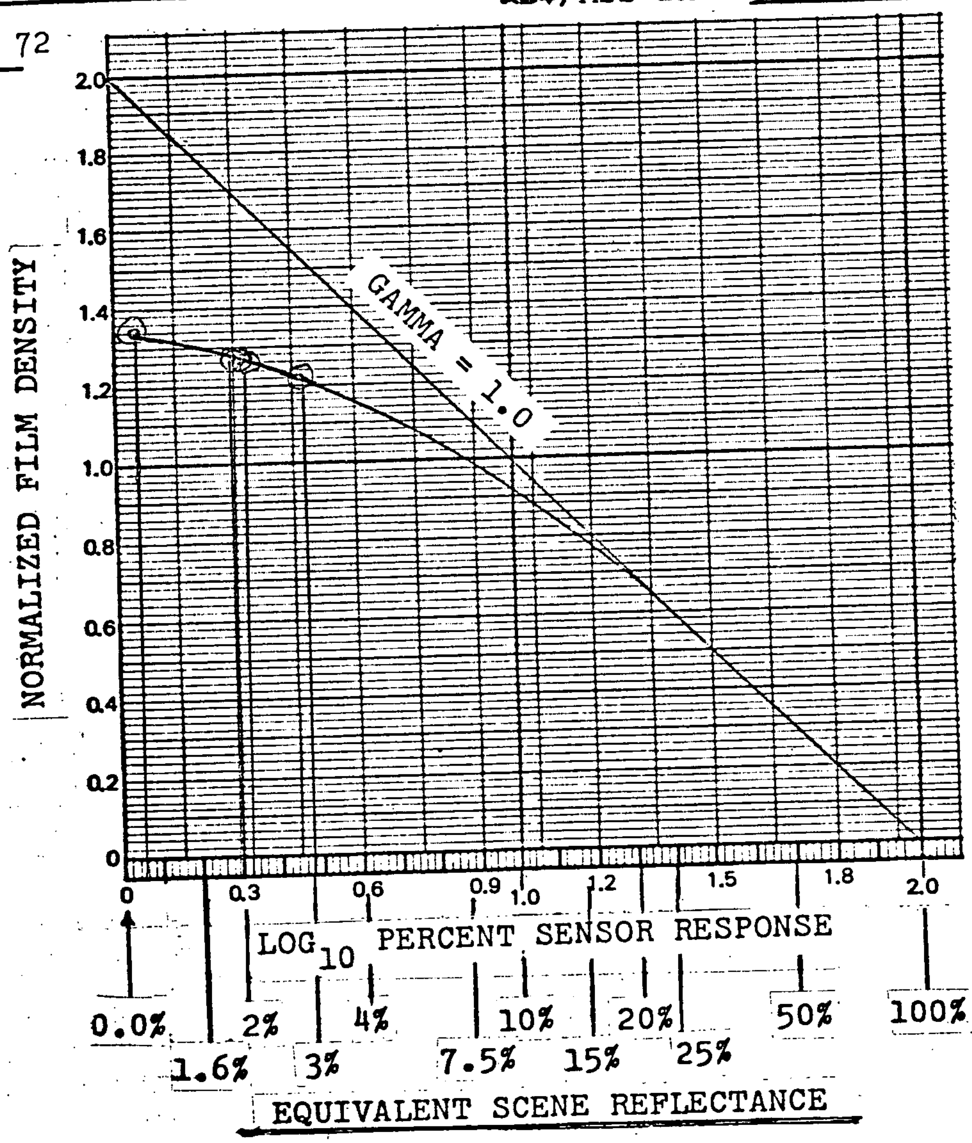


IMAGE CONTROL DENSITIES

		LESS CLOUD 0.58 D
CLOUD	- 0.58	0.00
DEEP WATER	- 1.85-1.92	1.27 - 1.34
SHALLOW WATER	- 1.80-1.84	1.22 - 1.26

Figure 6

MSS Band	Log % Sensor Response		% Scene Reflectance *	
	Deep Water	Shallow	Deep Water	Shallow
4	1.25 to 1.32	1.58 to 1.78	17.8% to 21%	38% to 60%
5	.96 to 1.04	1.28 to 1.34	9% to 11%	19% to 22%
7	.06 to .30	.36 to .48	1.2% to 2%	2.3% to 3%

* Relative to cloud at 100%

14. These data show clearly the order of atmospheric effects in the three spectral regions. In MSS-7, apparent water reflectance is 3% or less in both deep and shallow water. In MSS-5 (580-680 nm), deep water reflectance apparent to the sensor has increased to about 10%, 7% of which is probably caused by atmospheric haze, since yellow and red are not found in the clear ocean water. Increased reflectivity in the shallow water is attributable to red and yellow light reflected from the bottom. In the MSS-4 490-600 nm spectral region, recorded scene reflectances would be predominantly green and yellow. In this area of the Caribbean the color of the barren, deep water is blue, with a component of green from upwelling subsurface light, and reflected skylight not in excess of 3%-5%. The 18% to 21% apparent ocean scene reflectance is therefore mostly contributed by Rayleigh and Mie scattering in the atmosphere.

The net haze factor is estimated to be in the order of 15% in MSS-4 and will apply at least equally to the similar spectral region recorded by RBV-1. In MSS-5 the haze factor is about 6% to 8%, half that of MSS-4, and will apply to the RBV-2 image.

15. <u>Net Effect of Scene Contrast Degradation</u>

Figure 3 shows an average gamma gradient line drawn on the part of the curve between 4% and 10% sensor response, where it departs from linear γ 1.0 recording/reproduction, and where the ocean deep water surface will be recorded. Gamma in this region is about 0.60, and scene contrast will be reduced by that factor accordingly. In Figure 7, 15% and 7.5% haze curves have been plotted for MSS-4 and -5 images respectively, and gamma gradient lines have been drawn on them for the 4% to 10% scene reflectance regions. With 15% haze factor, the real γ 1.0 scene contrast is reduced to γ 0.19, and with 7.5% haze, to γ 0.42. The net effects of the gamma reductions are:

a. <u>In MSS-4</u> the deep water densities fall on the γ 1.0 linear part of the sensor response curve (Figure 4), and only correction for 15% haze is required. The final reproduction gamma correcting scene contrast in this image would be

$$\frac{\gamma\ 1.0}{\gamma\ .19} = \gamma\ 5.26.$$

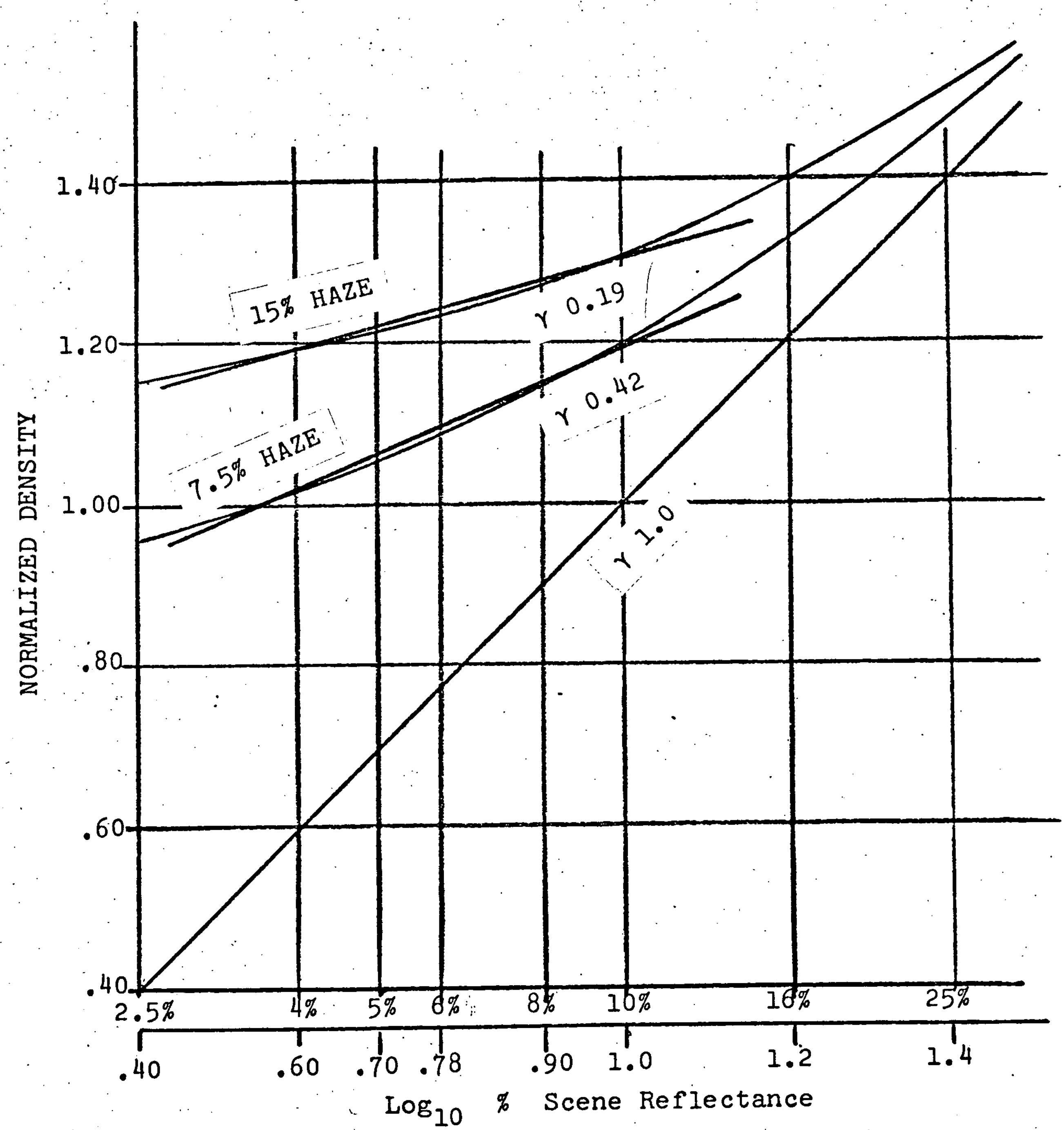


Figure 7 - Effect of 7.5% and 15% estimated haze factors in reducing 4%-10% scene reflectances from γ 1.0 to γ 0.42 and γ 0.19 respectively.

b. In MSS-5 the deep water densities fall on the non-linear part of the sensor curve, where gamma measures 0.75 $\left(\frac{\Delta D}{\Delta \log_{10} \text{Sensor Response}}\right)$. The effect of haze further reduces this to γ .42, the net gamma in this part of the image equalling .42 x .75, or γ 0.32. In restoring scene contrast, final reproduction gamma would then be $\frac{\gamma\ 1.0}{\gamma\ .32}$, or γ 3.12.

Provided the density ranges are matched, the two images so reproduced would then be equivalent in relative spectral scene reflectance and contrast. The density range and gamma of the negative image to be used as a mask with any positive can then be made to match the positive in opposite polarity.

16. Error Sources. Four main sources of error are inherent in this technique: Potential radiometric errors of 10% in the RBV and 6% in the MSS; gamma and density variations in the input images, the tolerances being $\gamma \pm 0.1$ and locally, 0.06 D to 0.10 D; the accuracy of density measurement with the MacBeth Model TD-102 Densitometer, $\pm$ 0.02 and in repeatability $\pm$ 0.01; and the accuracy of sensitometric control in each stage of image reproduction. In addition, the careful selection and density measurement of the same

part of the image scene in each spectral band must be considered. In the set of images being used, comparison of the GSFC step tablets indicates that gamma deviations do not exceed ± 0.05, and the use of the same cloud as reference for 100% sensor response adjusts the 2.0 useful image density range automatically. Many density readings on similar image areas in the different bands are consistently repeatable to an average of ±0.01D. By careful sensitometry, the reproduction stages are controlled within the reading tolerances of the densitometer, and each stage is plotted to confirm that key image densities are reproduced on the straight line of the reproduction material. The remaining largest unknown variables in the input images are local density differences may be 0.06 D to 0.10 D, and their radiometric errors.

17. However, with this particular image set, as shown in Figures 4, 5 and 6, the normalized data agree remarkably well with theory. It is concluded that in this image set, radiometric and local density variations are not large enough to drastically influence results obtained with this technique of interactive image processing for data reduction.

Ocean Water Color
Assessment from
ERTS-1 RBV and MSS
Imagery, MMC #538

D. S. Ross PR175

SIGNIFICANT RESULTS

1. Interpretation Techniques Development

a. Interactive Image Processing:

Stationary residual radiometric correction errors in RBV-1 and RBV-2 bulk processed 9.5-inch positive transparencies from ERTS-1 were substantially reduced, by photographic masking with negative equivalent RBV images taken over a relatively cloud-free ocean area. Reported at Symposium on Significant Results Obtained from ERTS-1, 5-9 Mar 73 NASA/GSFC (Paper I4) "Masking Bulk RBV Images to Reduce Stationary Residual Errors in Radiometric Correction"

b. Interactive Image Processing:

An MSS-4 negative combined with an RBV-2 positive was used to produce a new image, with the aim of cancelling image densities in a spectral region common to both images. The MSS-4 band records in the 490-600 nm region, and the RBV-2, 580 to 680 nm; 580 to 600 nm being included in both. This 20 nm part of the spectrum appears yellow-orange and is in a region where reflectance from sandy bottom in shallow water is transmitted. A shallow water area between North and South Bimini Islands, where such bottom reflectance is strong in the MSS-4 image, is cancelled in the new image made by masking. (ERTS-1 E 1007-15165 30 Jul 72)

c. Effects of the Atmosphere. ERTS-1 bulk processed images are closely held to a specified density range and reproduction gamma. By knowing, or estimating with reasonable accuracy, the percentage spectral reflectance of light and dark subjects in the images, a density normalization procedure has been worked out for estimating relative effects of the atmosphere in degrading scene contrast in the green and red images relative to the infrared MSS-7. Cloud and calm, clear water surfaces are used for light and dark references. The solution is largely graphical, and can account for changes in scene reproduction gamma at sensor response levels less than 20% of full response.

Ocean Water Color
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SIGNIFICANT RESULTS

2. Marine Resources & Ocean Surveys

a. Bathymetry (Alternatively, Interpretation Techniques Development, Image Enhancement)

Photo-optical and electronic density slicing were applied to ERTS-1 E 1007-15165-4, 30 Jul 72, an area in the Caribbean showing deep ocean water, and shallow areas on the Great Bahama Bank ranging from 0.5 meter or less to 18 meters. The density slicing processes were adjusted to correlate apparent water radiance to bathymetric contours shown on C&GS Chart 1112 (1:466,940). A number of large areas corresponding to water depths of 2 meters or less, 5 to 10 meters and 10 to about 20 meters were isolated by both processes. Where clear water and uniformly reflective bottom was found, clear of marine growths, the photo-optical and electronic image density slicing processes proved effective in delineating areas where depth was in the order of 5 meters, ± 1 meter. Results were reported at Symposium on Significant Results Obtained from ERTS-1, 5-9 Mar 73, NASA/GSFC (Paper M19).